Possible New Identifications for EGRET Sources

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ABSTRACT

The majority of the EGRET objects remain either unidentified or questionably identified at other wavelengths. We have conducted a multiwavelength study of several radio sources within or near the error boxes of EGRET unidentified sources at mid to high galactic latitude, under the hypothesis that the radio sources are blazars and are thus the best identification candidates for the EGRET objects. We show that one of these radio sources, PMN 0850-121, has a flux of 1.5 Jy at 22 GHz, and a nearly flat spectrum up to 230 GHz and is thus very likely to be the correct identification for the EGRET source 2EG J0852-1237.

Subject headings: Gamma Rays: observations — galaxies: active — quasars: individual (PMN 0850-121, PKS 2320-035, 2346+383) — BL Lacertae Objects: individual (1055+564)

1. Introduction

Though 59 EGRET sources have been identified as either blazars or pulsars, there remain 95 sources which have not yet been identified with objects at other wavelengths (Thompson *et al* 1996). Mc Laughlin *et al* 1996 hypothesize that many of the nonvariable unidentified sources are part of a broad galactic population, possibly pulsars. Due to EGRET's diminishing efficiency, we may not learn much more about the high energy gamma-rays (eg. positions or variability) from these sources until the next mission. Any further insights on these sources in the intervening time will most likely be gained at other wavelengths. We have therefore initiated a multiwavelength radio/millimeter-wave study in order to assess the credibility of possible counterparts. Mattox *et al* 1997 determine, from the Green Bank Survey radio catalogues, which flat spectrum radio sources are within or near the error boxes of each EGRET source. Based on the flux density of the radio source at 4.85 GHz, the spectral index between 1.4 and 4.85 GHz, and the candidate source's position within the EGRET error ellipse, they calculate an *a posteriori* probability that the candidate source is a correct identification for the EGRET source. From their lists, we have extracted 4 sources, with relatively high probabilities for identification, and we have included them in our multiwavelength study. We are working under the hypothesis that these sources are blazars, and are the sources of the gamma-rays. To our knowledge, these sources all previously only had non-simultaneous measurements at the two frequencies of the Green Bank Survey (1.4 and 4.85 GHz), and no other observations except for non-simultaneous optical observations (by other observers) to determine redshifts and magnitudes. Our main goal is to obtain quasi-simultaneous centimeter to millimeter-wave spectra to determine whether each flat spectrum radio source has blazar properties. Certain blazar properties which are correlated with gamma-ray detection by EGRET, such as a flat spectrum down to millimeter wavelengths, and/or significant variability, would lead to an even higher probability for identification than that from the formal calculation (Mattox *et*

al 1997). In section 2 we describe the observations, in section 3 we analyze the spectra of each object and assess the possibilities of new identifications and in section 4 we present our conclusions and discuss our future work.

2. Observations

The sources, positions. and flux densities at each frequency are listed in Table 1. Column (1) gives the name of the EGRET source; Column(2) the name of the radio source that is a potential identification; Column(3) gives the redshift if known; Column (4) gives the type of object, if known; Columns (5) and (6) give the J2000 celestial coordinates; right ascension (RA) in hh mm ss; declination (DEC) in dd mm ss. For most sources, this position is the radio position as found by the NASA Extragalactic Database (NED), but for PMN 0850-121 we have used the more accurate optical position (Mattox *et al* 1997;Halpern and Eracleous 1997). Columns (7-12) give the averaged flux densities (with typical uncertainties) at the respective frequencies (in Jy); Column (13) gives the spectral index between 2.25 and 22 GHz. For the sources that do not have data at 22 GHz, we have calculated the spectral index between 2.25 and 8.3 GHz. In this table, and throughout this paper we use the convention $F_\nu \propto \nu^\alpha$.

We have used the 13.7 meter antenna of Metsähovi Radio Research Station (details of observing methods can be found in Teräsranta *et al* 1992) to observe at 22 and 37 GHz as part of a regular monitoring program of blazars and blazar candidates. The observations were conducted 20 Mar 1997 and 1 Apr 1997. As part of this same program, two of these sources (PMN 0850-121 and PKS 2320-035) were observed at 90 and PMN 0850-121 was observed at 230 GHz with the Swedish-ESO Submillimeter Telescope (Tornikoski *et al* 1996). The remaining sources were either at declinations too high to be seen from Chile, or were too close to the Sun. These observations were conducted on 1 Apr 1997 and again on

31 Apr/1 May. Each of our sources was monitored regularly (usually more than once per week) with the 2 element Green Bank Interferometer (one antenna of the 3 element array is not used for monitoring studies) at 2.25 and 8.3 GHz. Each antenna is 26 meters and the baseline is 2400 meters. The observations were conducted between 25 Mar 1997 and 12 May 1997. (see Waltman *et al* 1996 for details of the GBI). The centimeter–millimeter range was picked because the known EGRET blazars have spectra which are nearly flat in this range (Bloom *et al* 1994) and it is generally believed that a ~ 1 Jy source with a flat centimeter to millimeter spectrum in the error box is a good candidate for identification. The observations were not precisely simultaneous, but were all within a few days of each other, with the 2.25 and 8.3 GHz observations continuing after the higher frequency observations were conducted. The gamma-ray observations (from a much earlier time frame) are summarized in Thompson *et al* 1995 and Thompson *et al* 1996.

3. Discussion

We find that these sources, when observed simultaneously between 2.25 and 22 GHz show a nearly flat or rising spectrum. This is an important result, since previous estimates of spectral indices in this range were based on measurements taken years apart and flat spectrum sources are known to vary significantly at centimeter wavelengths over months to years. The source PMN 0850-121 is brighter than 1 Jy from 22 to 230 GHz, and is within the 95% confidence contour of the test statistic map for the associated gamma-ray source. By the standard of Thompson *et al* 1995, this source would be considered a positive identifcation, although, since the source is roughly 0.5 Jy at 5 GHz, the identification probability, $p(id|r)$, of Mattox *et al* 1997 is about 0.05, much lower than that of the 42 strong EGRET identifcations which he lists. On the other hand, α_{90-230} is -0.2, which is roughly similar to the millimeter spectral inidces for EGRET sources as determined in

Bloom *et al* 1994($\langle\alpha\rangle$=-0.54), and considerablly flatter than α_{90-230} for similar blazars not detected by EGRET ($\langle\alpha\rangle = -0.75$). Over the $\sim$ 1.5 months of GBI observations for PMN 0850-121, the 2.25 GHz data show a 10 % increase and the 8.3 GHz show a 20 % increase in flux density. Though the systematic uncertainties are estimated to be at roughly the same level as this variability, an analysis of several calibration sources shows (Waltman 1997) that this long term increase is not a systematic effect. The smaller time-scale (and amplitude) increases seen throughout the 2.25 GHz observations are likely caused by scinitillation (Waltman 1997). In addition, Halpern and Eracleous 1997 report that this source is highly variable at optical wavelengths, with a flare of about 2 magnitudes from Feb 1996 to Feb 1997 (the time-scale of variation within that period is unkown). These data suggest that there may have been a small amplitude centimeter-wave flare following an earlier optical outburst by several months. Such activity has been seen in EGRET detected blazars, such as 0836+710 (Reich *et al* 1993); however, we do not have enough data to pin-point the relative amplitudes or times of the flares.

Considering its contemporaneously measured spectrum, the formal value of $p(id|r)$ for PMN 0850-121 is likely to be an underestimate of the true probability that this is the correct EGRET identification. For the remaining sources, though their spectra above 22 GHz are not generally known, it is clear that B1055+5644 and B2346+3832 have flat spectra up to this point, and that PKS 2320-035 has a slowly decreasing spectrum up to 90 GHz. Though they are not extraordinarily bright, spectral flatness up to 22 GHz make them stronger candidates for EGRET identifcation than the lower frequency data alone. Since many millimeter flares only propagate down to several GHz with a much lower amplitude, and with delays of months, data at lower frequencies (less than 20 GHz) should only be used as a rough guidline for source variability and possible identifcation with gamma-ray sources. PKS 2320-035 has a slightly higher flux density at 5 GHz (interpolated from measured values) and a flatter spectral index, making $p(id|r)$ higher than the value of Mattox *et al*

1997, but still not quite as high as the identifications considered to be firm. However, the observations at 90 GHz show that the true probability for a positive identification is likely to be higher. This source had continuously *decreasing* flux density at 2.25 and 8.3 GHz by about 10 % .

4. Conclusions and Future Work

We conclude that the source PMN 0850-121 is firmly identified with an EGRET source, and that several other candidate sources from this study, though probably blazars, are too dim to be considered *firm* identifications. However, future monitoring may reveal that these sources have higher centimeter/millimeter states. In addition to the total flux density data at centimeter to submillimeter wavelengths, VLBI observations will also add to our knowledge of these sources. In general, multiwavelength monitoring of candidate EGRET sources should be conducted on a wider scale to see whether more unidentified sources at mid to high galactic latitudes are blazars.

We would like to thank J. Mattox for supplying us with the code to determine identifcation probabilities using the Green Bank survey data. We would also like to thank E. Waltman and F. Ghigo for consultation on the GBI Data. The GBI is a facility of the National Science Foundation operated by NRAO with support from the NASA High Energy Astrophysics Program. This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboatory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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Figure Captions

Fig. 1.— The 2.25 and 8.3 GHz data for PMN 0850-12. The 2 GHz data is represented by filled circles, and the 8 GHz data is represented by open diamonds. The modified Julian day (JD-2400000.5) is for the period March 25-12 May 1997

Fig. 2.— The 2.25 and 8.3 GHz data for 1055+564

Fig. 3.— The 2.25 and 8.3 GHz data for PKS 2320-035

Fig. 4.— The 2.25 and 8.3 GHz data for 2346+383

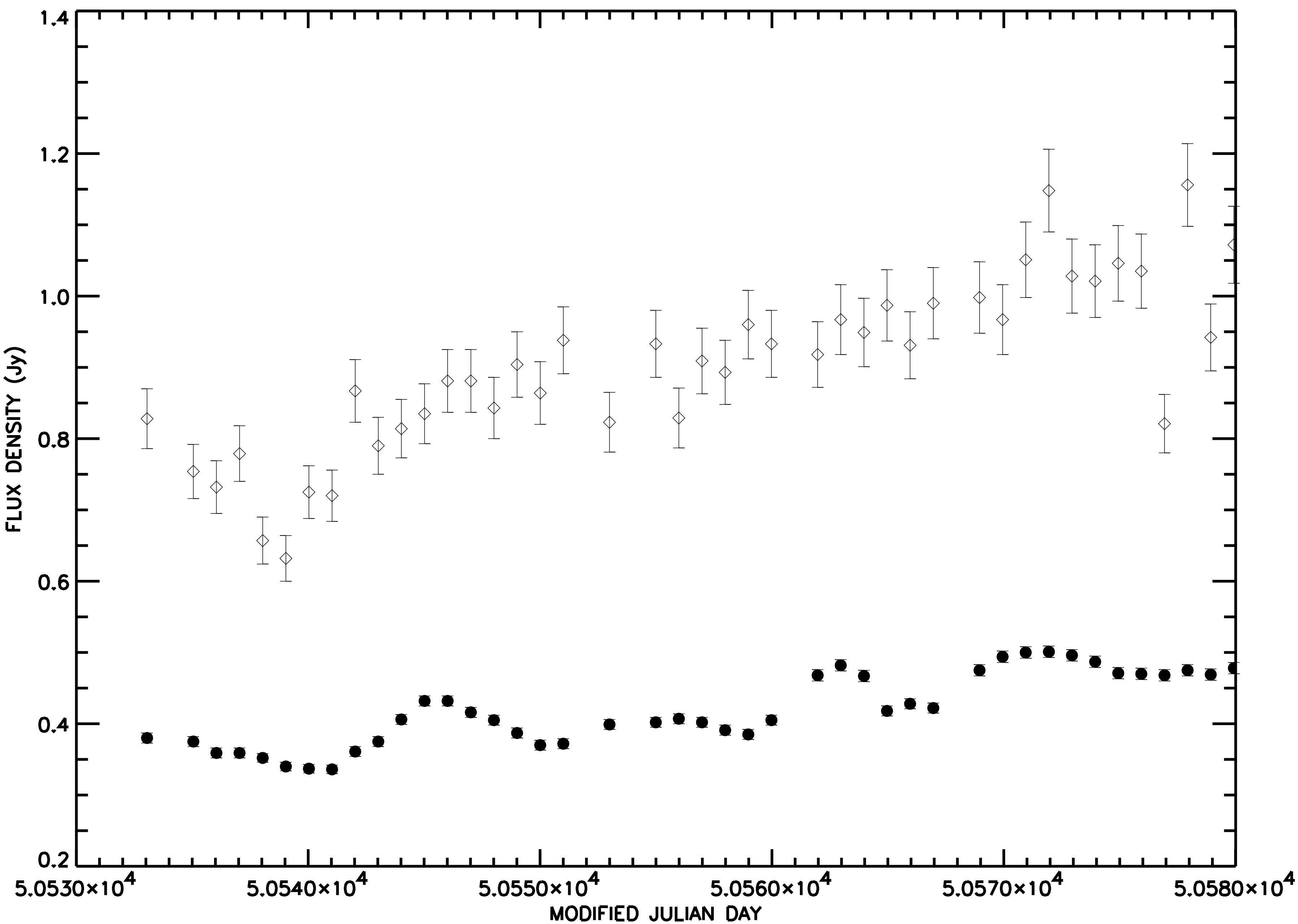

FLUX DENSITY (Jy)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
5.0530×10^4
5.0540×10^4
5.0550×10^4
5.0560×10^4
5.0570×10^4
5.0580×10^4
MODIFIED JULIAN DAY

FIG. 2

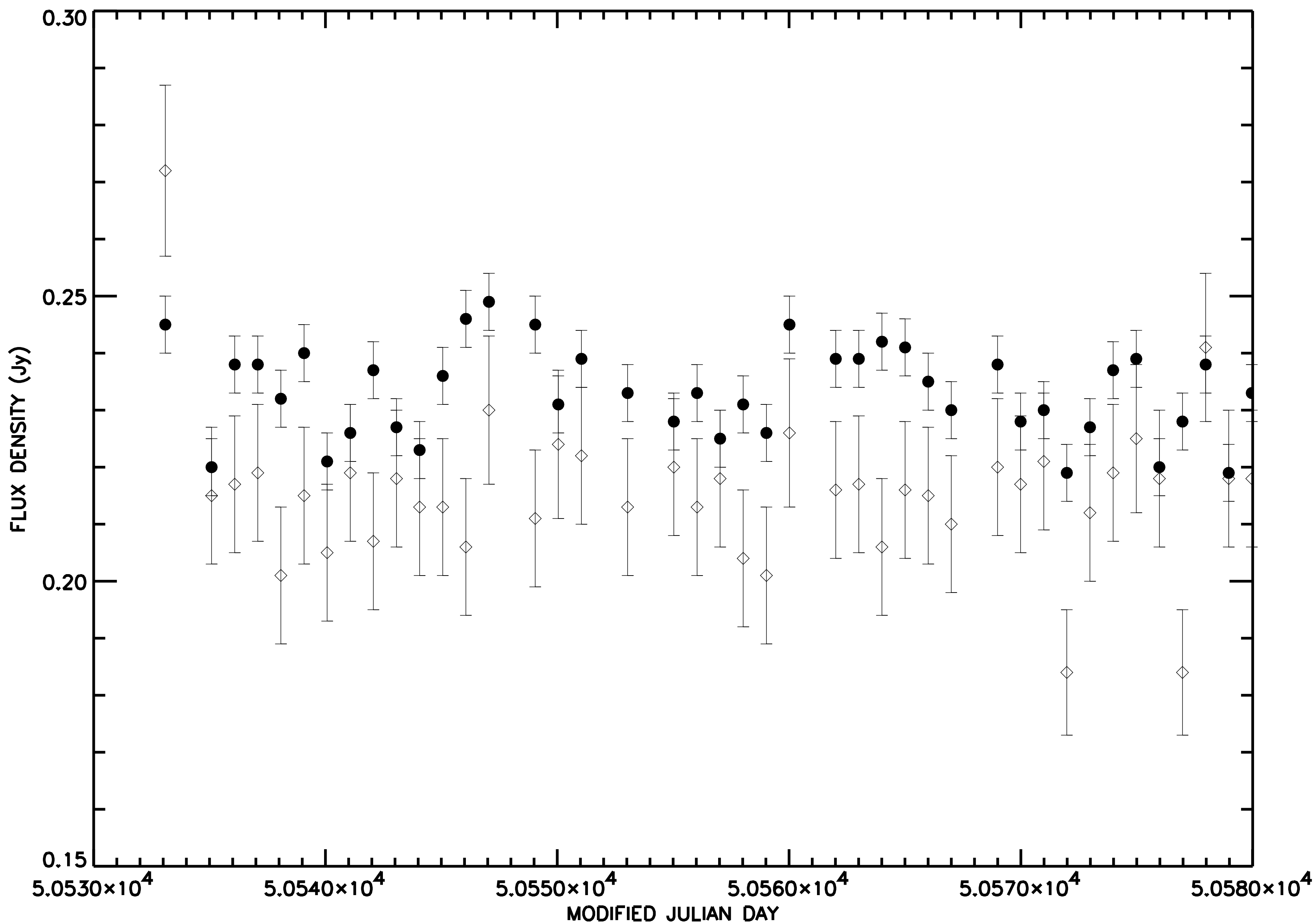
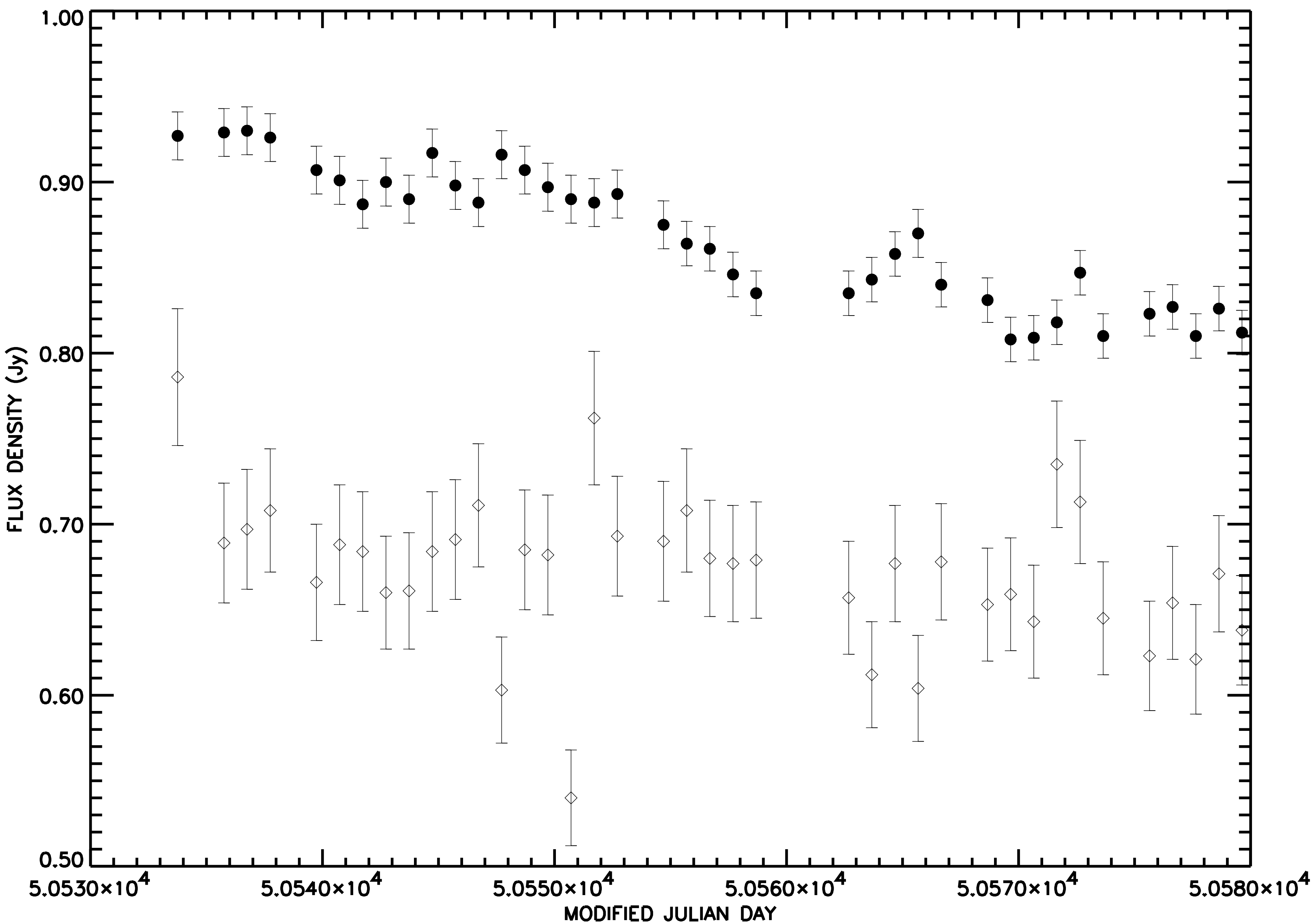
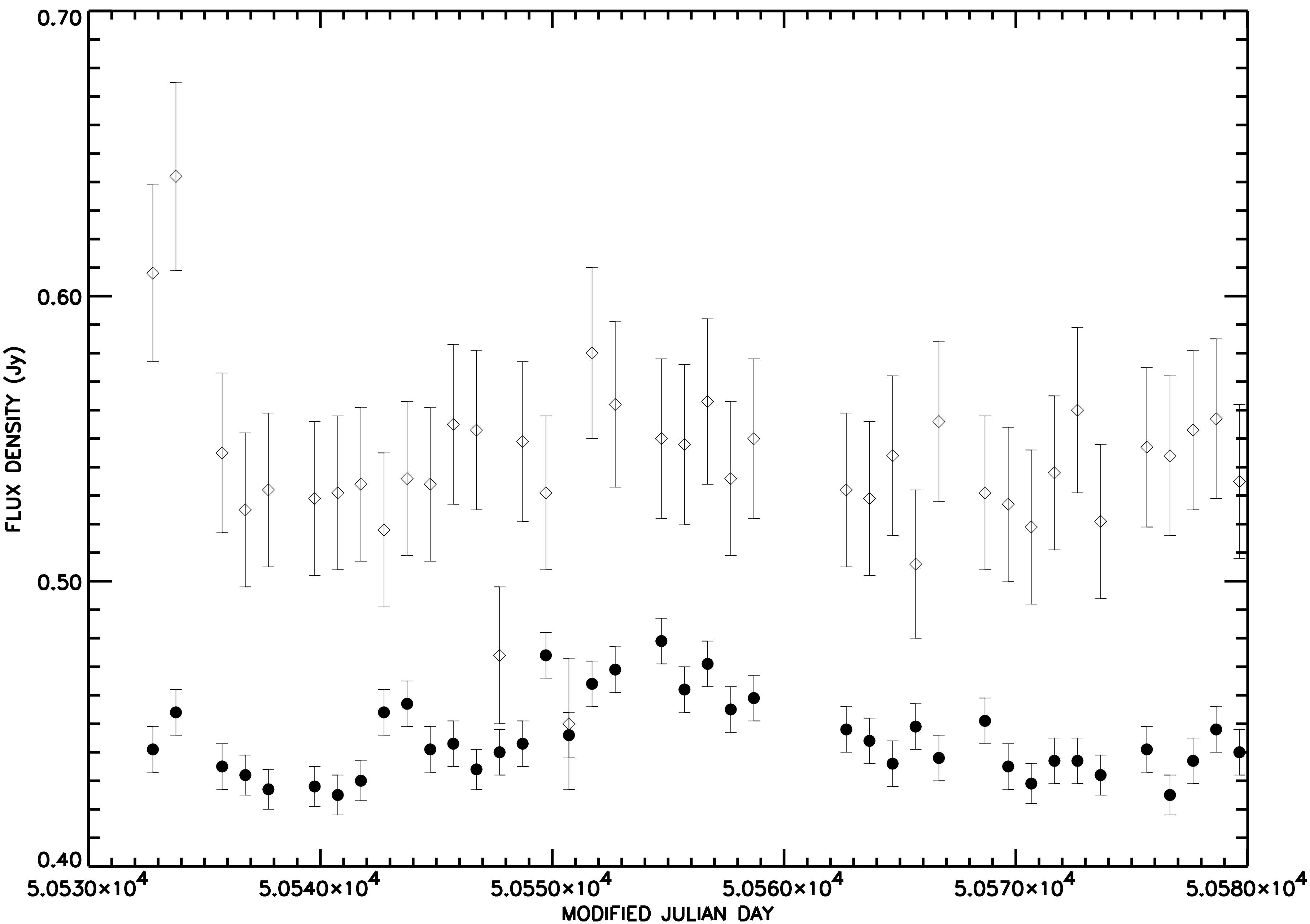

FLUX DENSITY (Jy)
0.30
0.25
0.20
0.15
5.0530×10^4
5.0540×10^4
5.0550×10^4
5.0560×10^4
5.0570×10^4
5.0580×10^4
MODIFIED JULIAN DAY

FIG. 3



FLUX DENSITY (Jy)
1.00
0.90
0.80
0.70
0.60
0.50
5.0530×10⁴
5.0540×10⁴
5.0550×10⁴
5.0560×10⁴
5.0570×10⁴
5.0580×10⁴
MODIFIED JULIAN DAY

FIG. 4



FLUX DENSITY (Jy)
0.70
0.60
0.50
0.40
5.0530×10^4
5.0540×10^4
5.0550×10^4
5.0560×10^4
5.0570×10^4
5.0580×10^4
MODIFIED JULIAN DAY

TABLE 1

Summary of Observations

EGRET Source (1)	Potential ID (2)	z (3)	Type (4)	RA (5)	DEC (6)	2.25 GHz (7)	8.3 GHz (8)	22 GHz (9)	37 GHz (10)	90 GHz (11)	230 GHz (12)	S.I. (13)
2 EG J0852-1237	PMN 0850-1213	0.566	QSO	08 50 09.6	-12 13 34	0.410 ±0.007	0.861 ±0.045	1.43 ±0.06	1.49 ±0.08	1.19±0.20	1.01±0.08	0.57
2 EG J1054+5736	B1055+5644	0.41	BL Lac	10 58 37.7261	56 28 11.183	0.215 ±0.005	0.233 ±0.012	0.25 ±0.05	···	···	···	0.06
2 EGS J2322-0321	PKS 2320-035	1.41	QSO	23 23 31.9537	-03 17 05.023	0.837 ±0.013	0.666 ±0.034	···	···	0.55 ± 0.08	···	–0.17
2 EG J2354+3811	B2346+3832	1.03	QSO	23 49 20.826	38 49 17.572	0.443 ±0.008	0.538 ±0.034	0.48 ±0.07	···	···	···	0.04